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(54) **OPTICAL ADD/DROP MULTIPLEXER USING INTEGRATED OPTICAL COMPONENTS**

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(22) Filed: **Nov. 18, 2011**

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Related U.S. Application Data

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(51) **Int. Cl.**
H04J 14/02 (2006.01)

(52) **U.S. Cl.**
CPC ***H04J 14/0213*** (2013.01); ***H04J 14/0212*** (2013.01); ***H04J 14/0217*** (2013.01)

(58) **Field of Classification Search**
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USPC 398/68, 83–85
See application file for complete search history.

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(57) **ABSTRACT**

An optical add/drop multiplexer incorporates an integrated receiver module and an integrated transmitter which are interfaced to an intervening electrical network to provide an add/drop/pass-through functionality. The receiver module incorporates a wavelength demultiplexer which is in turn combined with optical/electrical converters PIN photodiodes, and amplifiers on a per wavelength basis to output a plurality of parallel electrical signals in response to a common optical input. The transmitter module combines an integrated plurality of drive circuits and lasers for converting a plurality of parallel input electrical signals to a plurality of optical signals, on a per wavelength basis, which in turn are coupled via an optical wavelength multiplexer to a common output optical fiber. The interconnected electrical network, ring mesh or tree, can provide a reconfigurable electrical add/drop interface to other portions of the network.

8 Claims, 5 Drawing Sheets

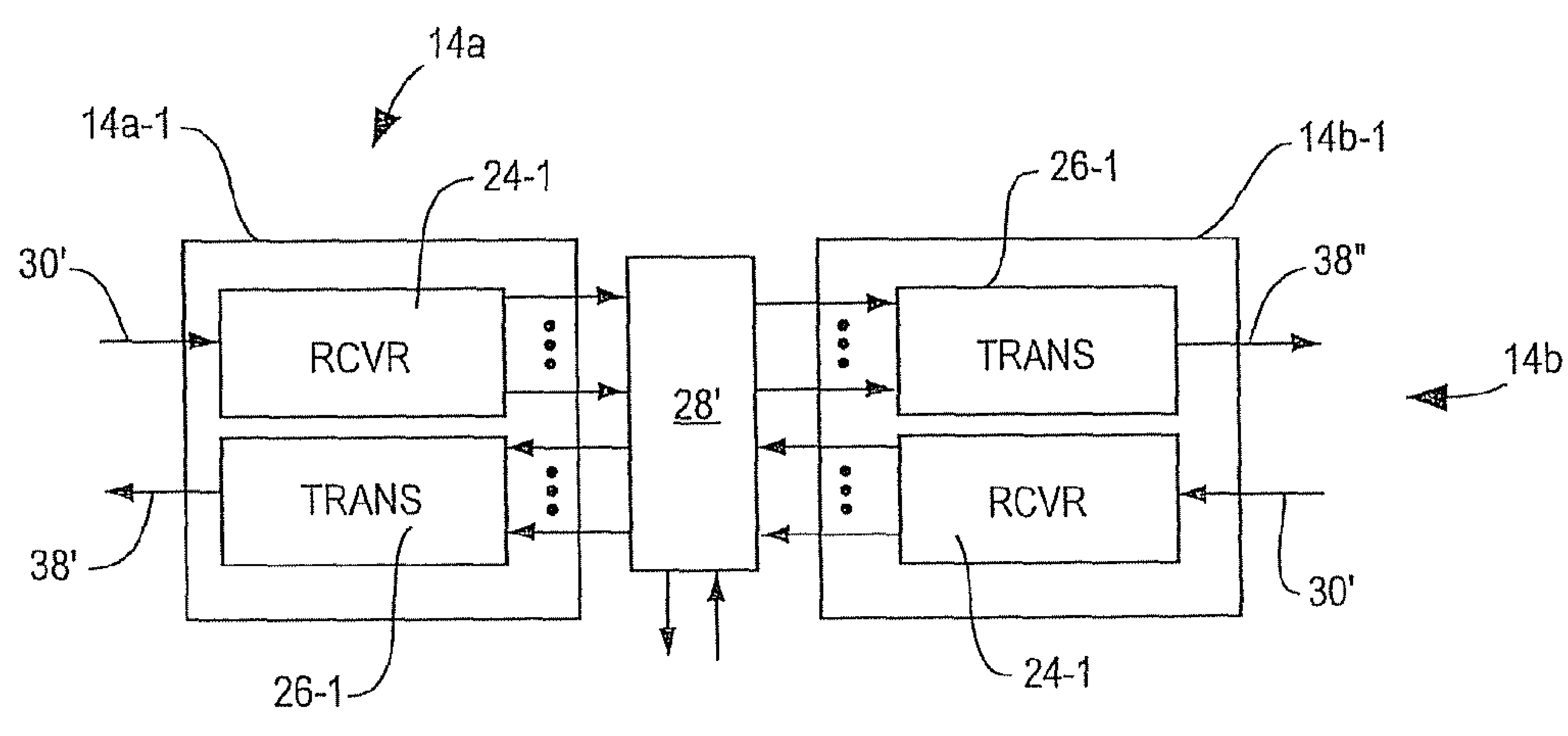


FIG. 1

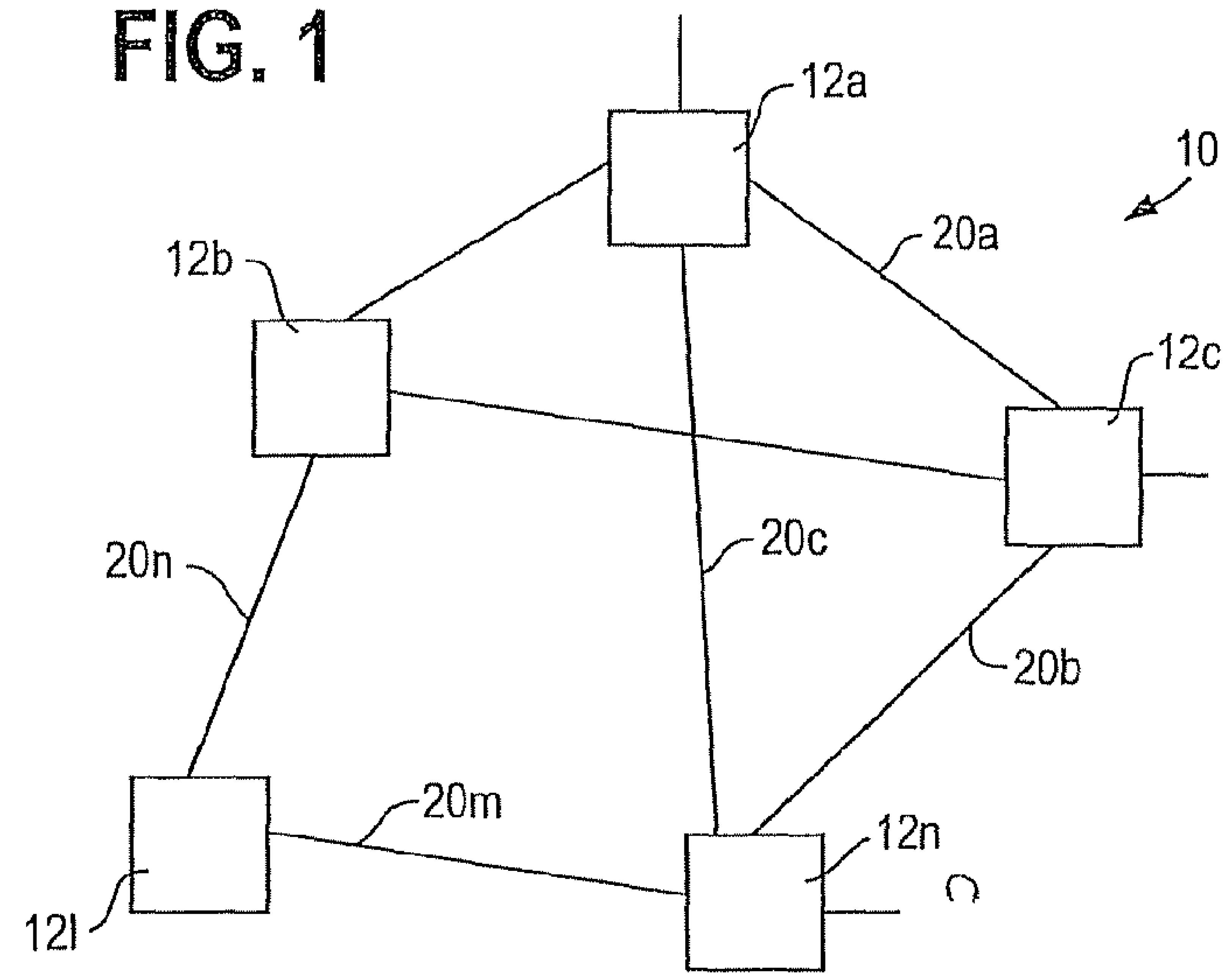


FIG. 2A

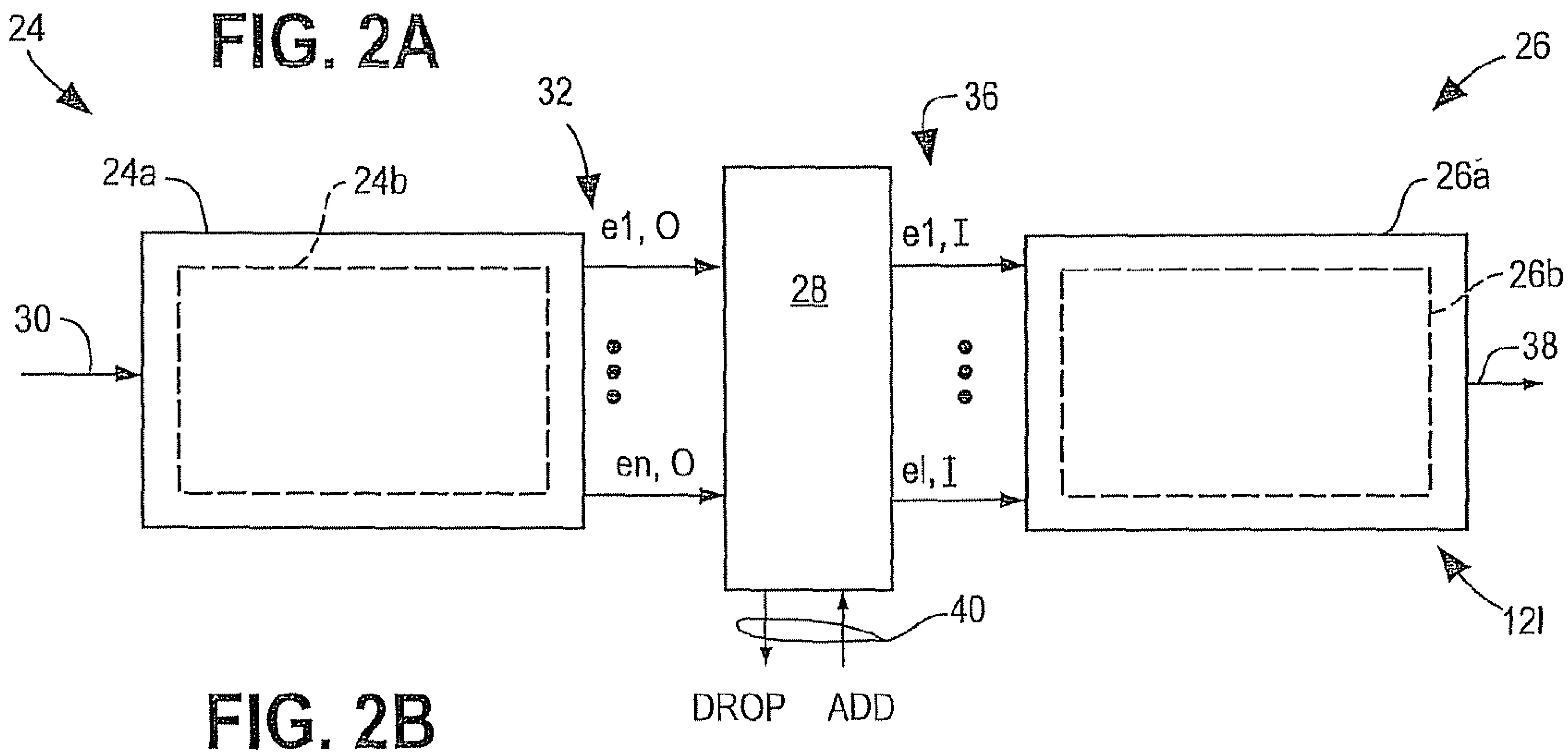


FIG. 2B

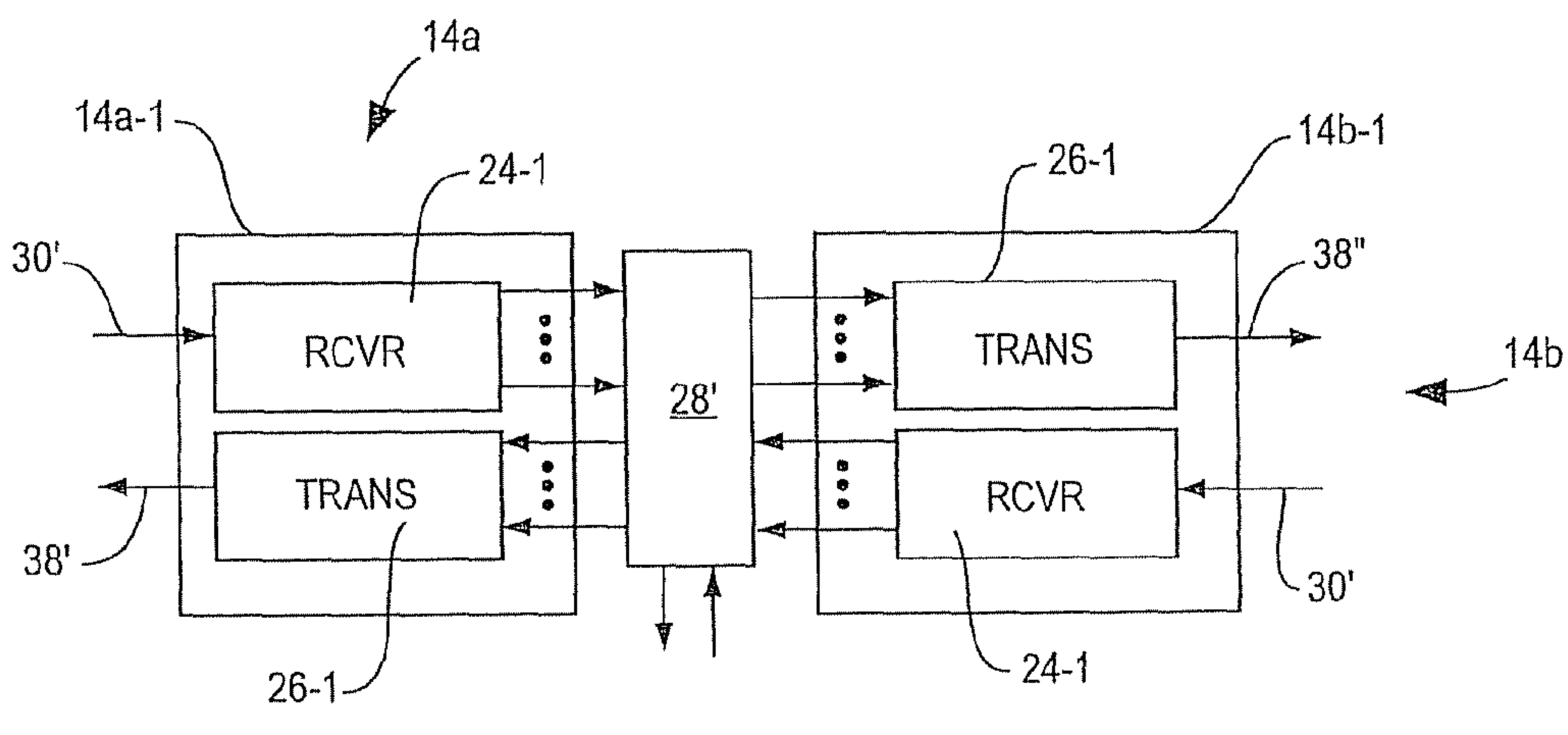


FIG. 4

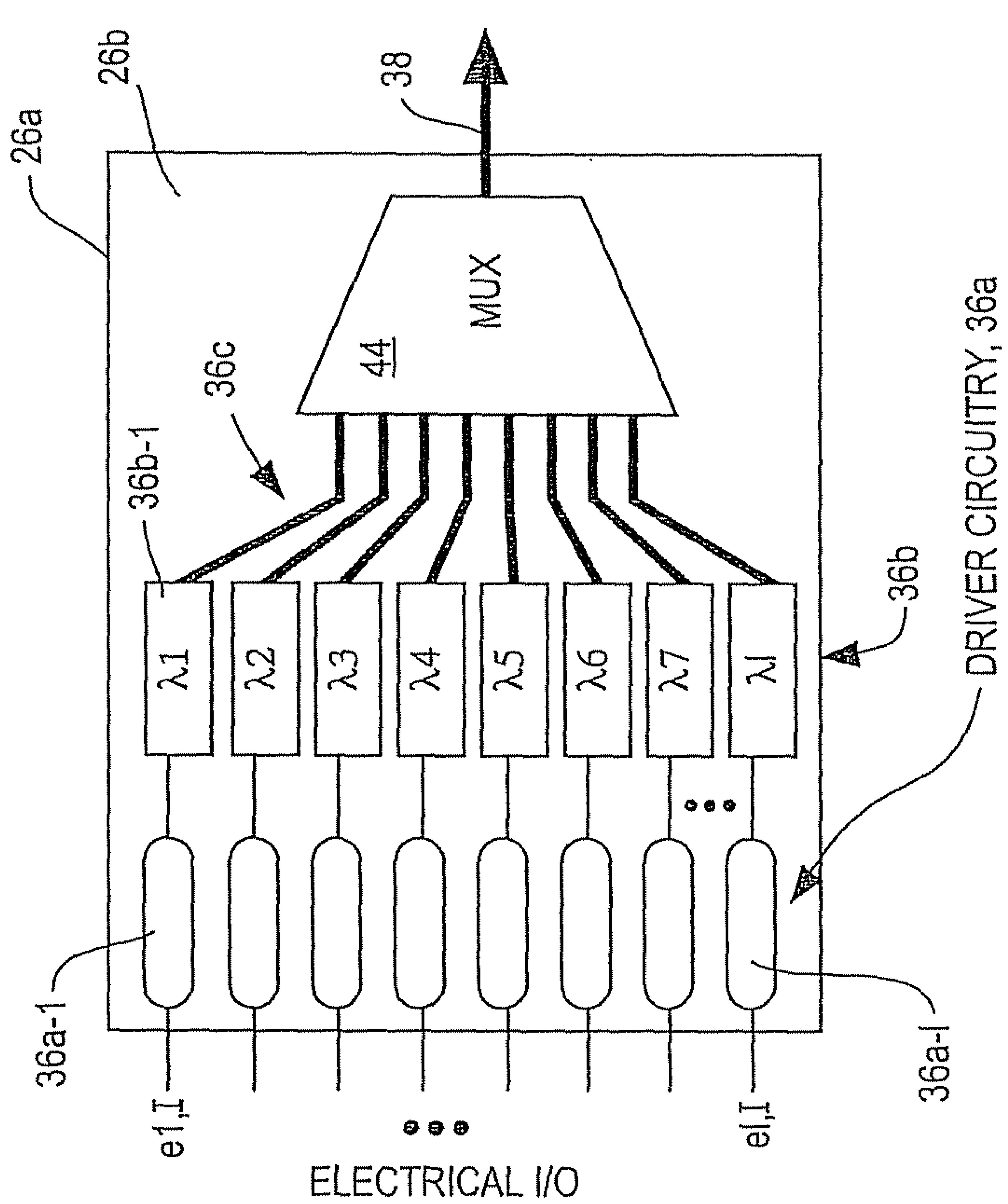

26
26a
26b
38
MUX
44
36c
36b-1
λ1
λ2
λ3
λ4
λ5
λ6
λ7
λl
36b
DRIVER CIRCUITRY, 36a
36a-1
36a-l
e1,I
el,I
ELECTRICAL I/O

FIG. 3

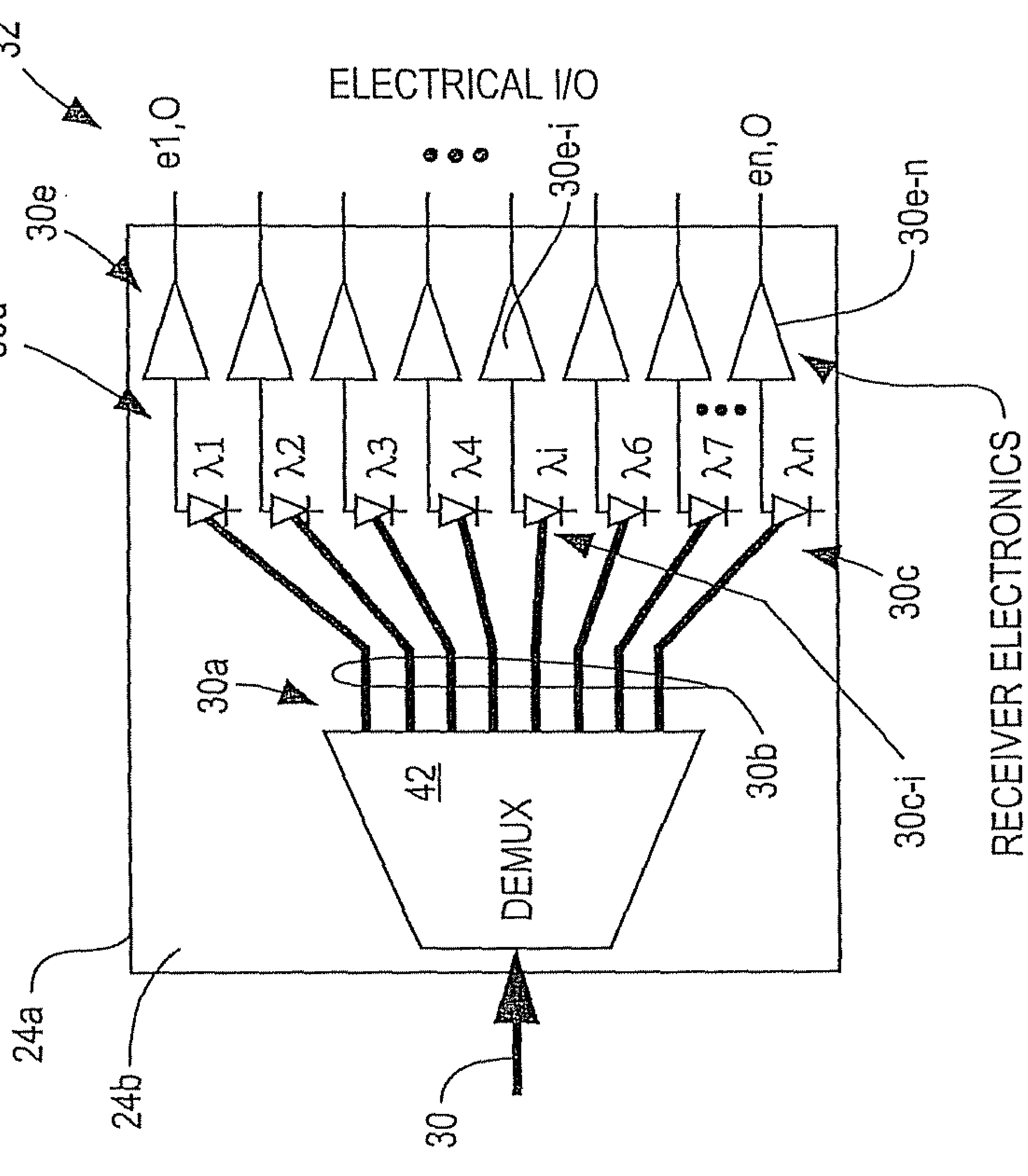

24
32
ELECTRICAL I/O
e1,O
en,O
30e
30e-i
30e-n
30d
λ1
λ2
λ3
λ4
λi
λ6
λ7
λn
RECEIVER ELECTRONICS
30c
30c-i
30a
30b
42
DEMUX
24a
24b
30

FIG. 5

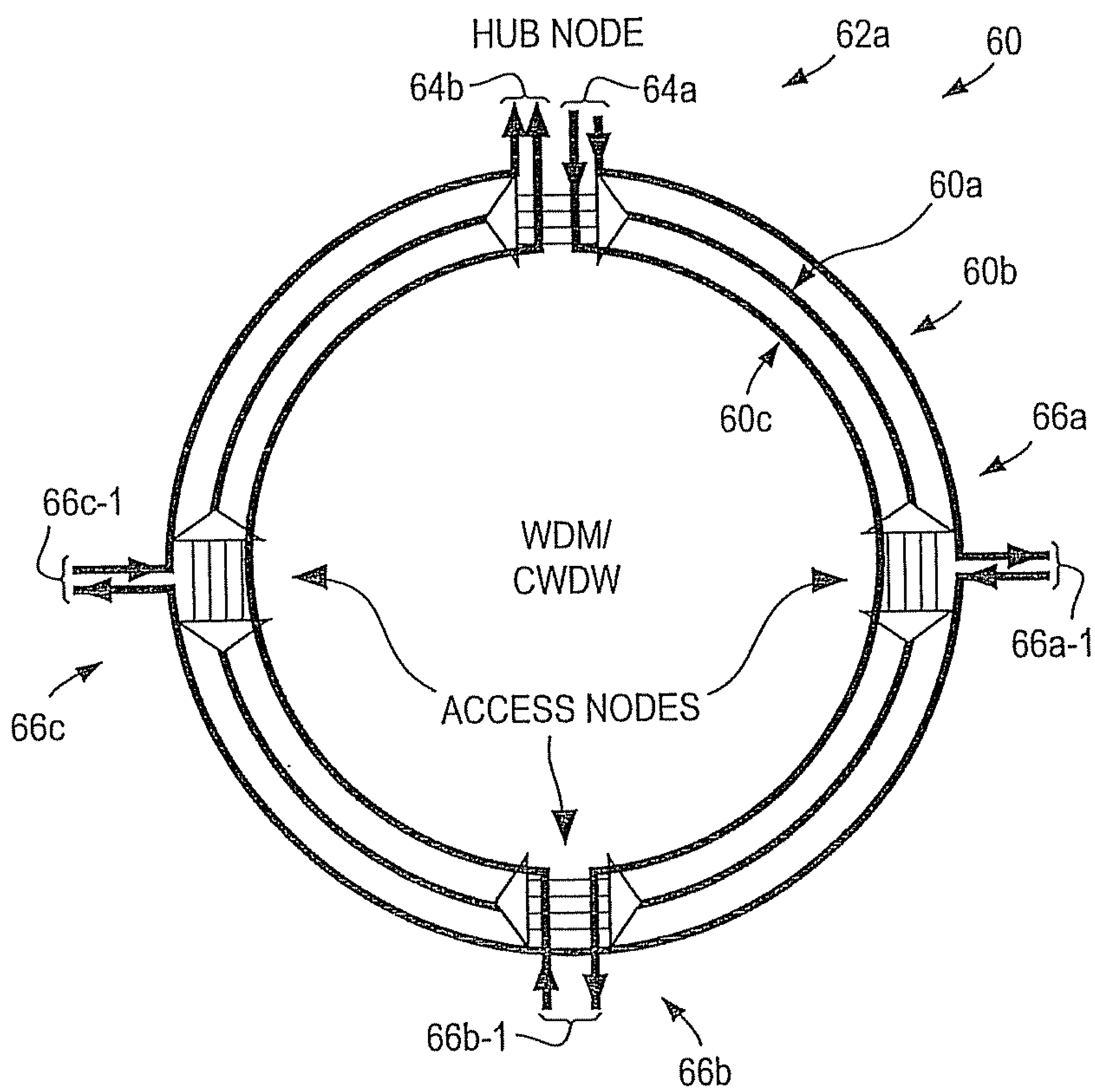

HUB NODE
62a
60
64b
64a
60a
60b
60c
66a
66c-1
WDM/
CWDW
66a-1
66c
ACCESS NODES
66b-1
66b

FIG. 6

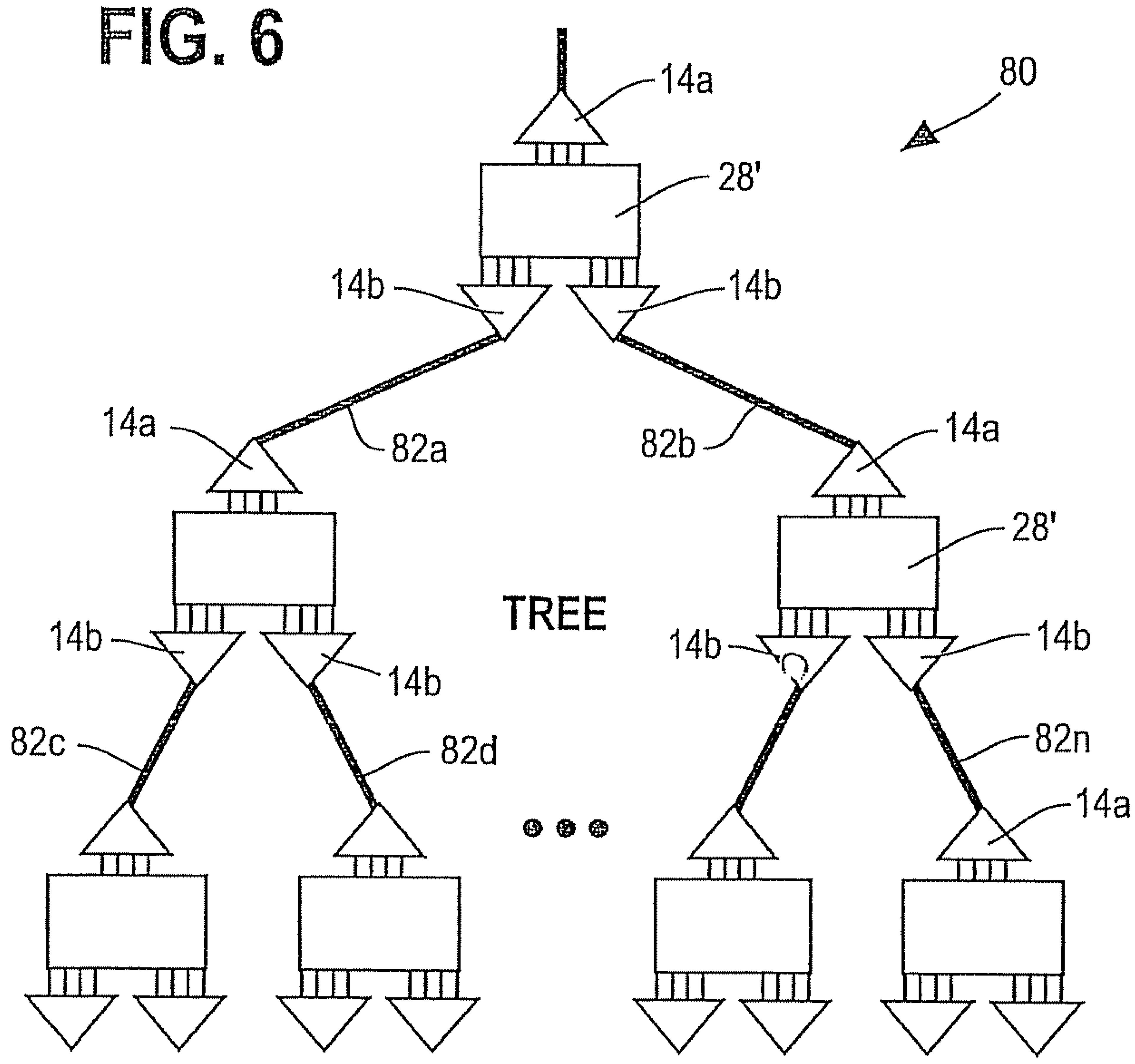

80
14a
28'
14b
14b
14a
82a
82b
14a
28'
TREE
14b
14b
14b
14b
82c
82d
82n
14a

FIG. 7

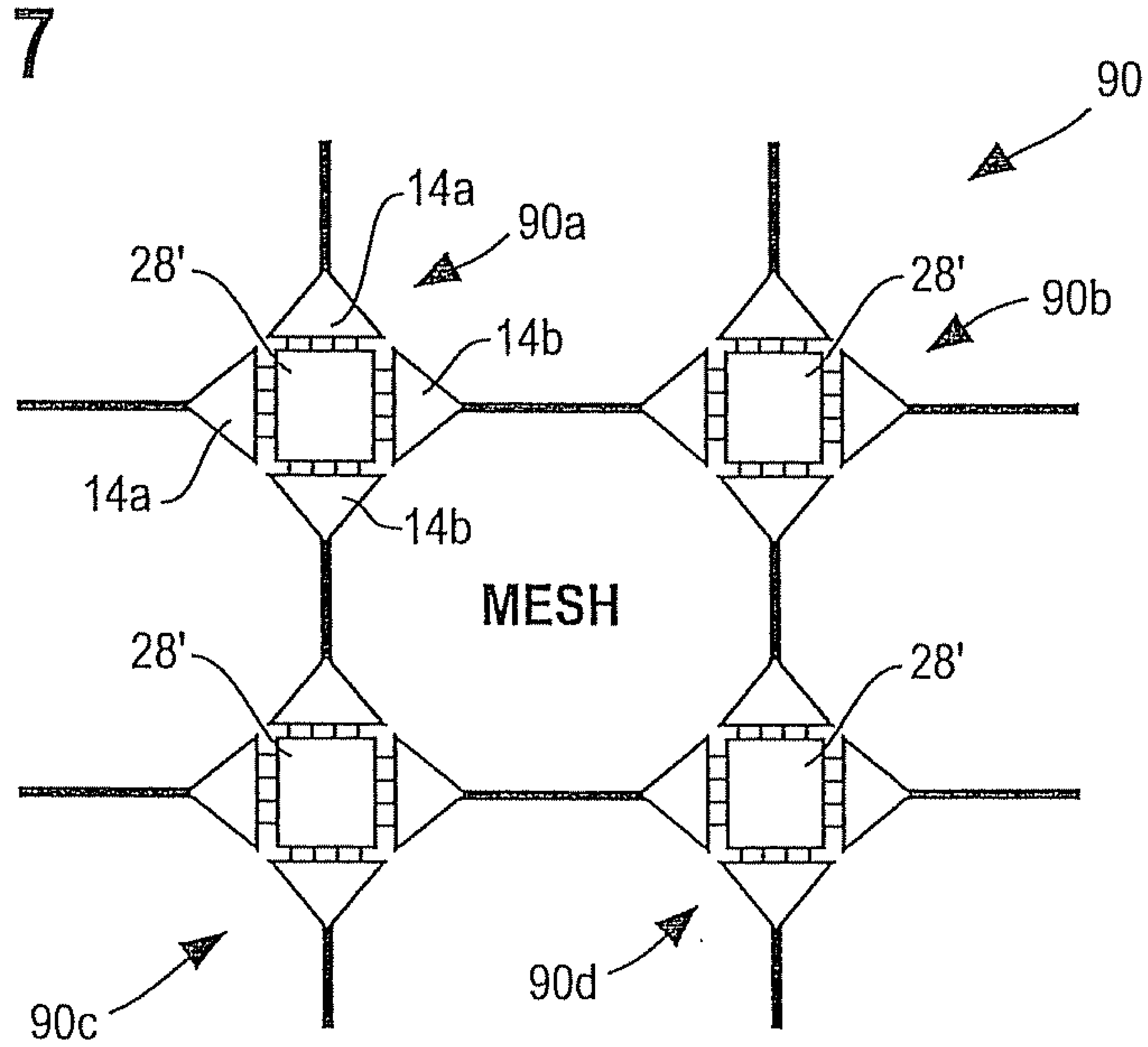

90
14a
90a
28'
28'
90b
14b
14a
14b
MESH
28'
28'
90c
90d

FIG. 8B

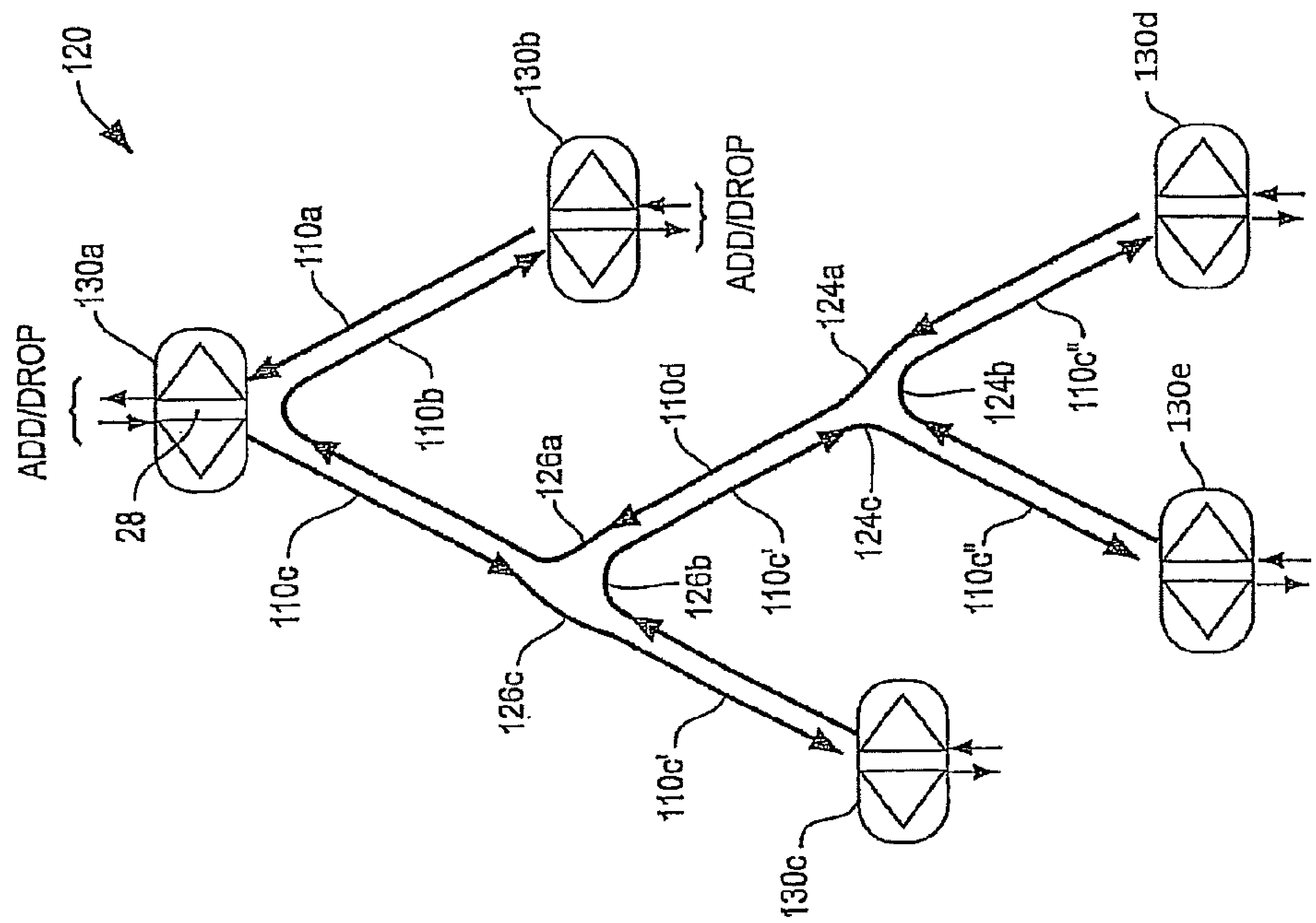
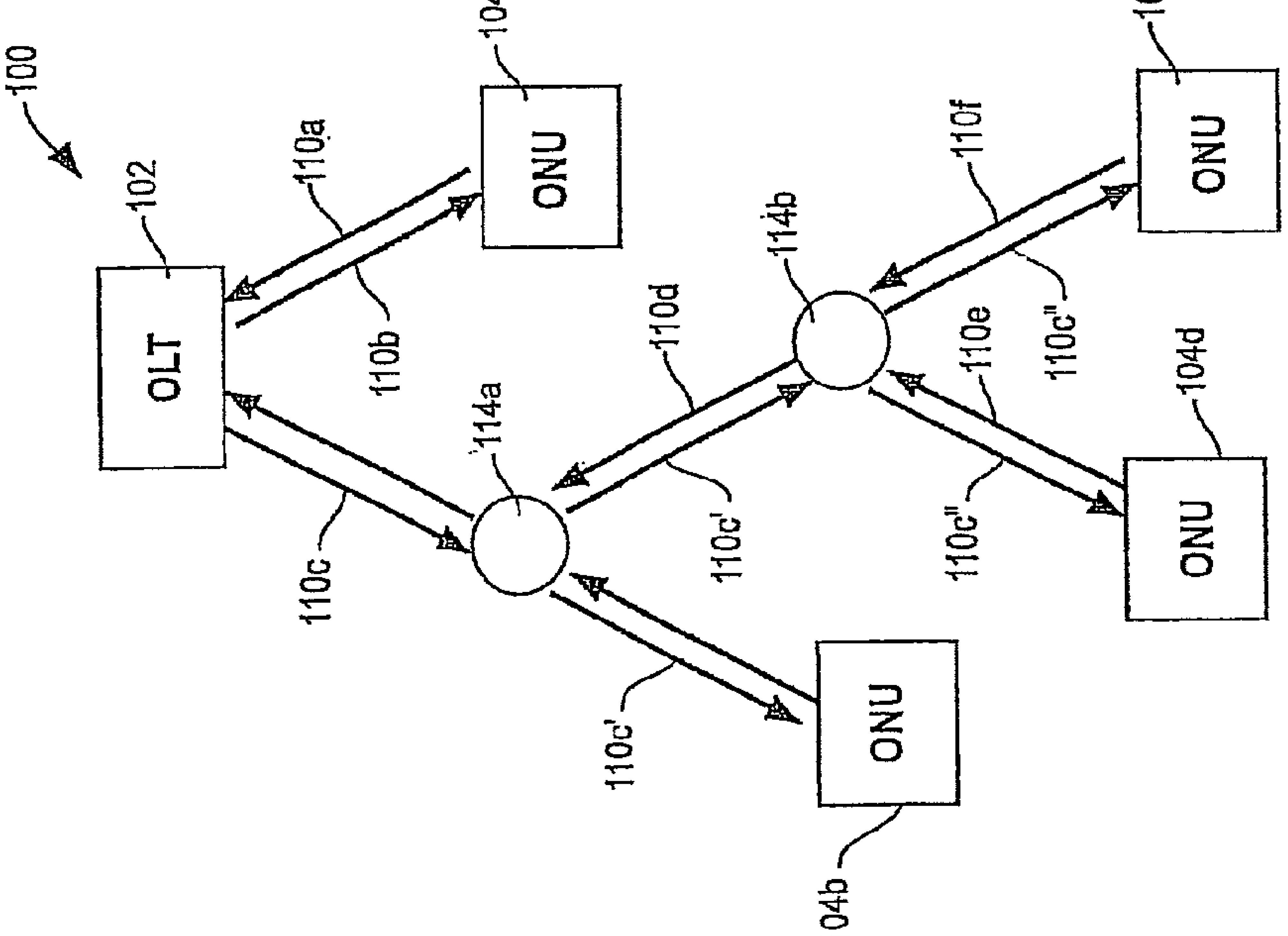


FIG. 8A
PRIOR ART



OPTICAL ADD/DROP MULTIPLEXER USING INTEGRATED OPTICAL COMPONENTS

CROSS-REFERENCE TO RELATED APPLICATION

This application is a divisional of parent U.S. patent application filed May 13, 2002 as application Ser. No. 10/144,674 and claims the benefit of the filing date thereof. The benefit of the filing date of Provisional Patent Application Ser. No. 60/291,506, filed May 16, 2001 is also hereby claimed.

FIELD OF THE INVENTION

The present invention relates to the field of optical networking. More specifically, the present invention relates to integrated optical add/drop multiplexers.

BACKGROUND OF THE INVENTION

In known optical communications systems, optical/electrical interfaces are created at nodes. In known Wave Division Multiplexing (WDM) Systems modulated information carrying light beams of selected wavelengths transmitted on a common fiber, can be added/dropped while others are passed-through at each node using such interfaces.

The interfaces need to accommodate a variety of rates and data formats (transparency) and be remotely configurable. One such interface is an optical add/drop multiplexer. Such multiplexers find application in optical networks of the type disclosed in U.S. Pat. No. 6,301,254B1, Virtual Path Ring Protection Method and Apparatus. The '254 patent is assigned to the assignee hereof and is incorporated by reference.

Known multiplexers are often formed of discrete components which require numerous connections. They are expensive to fabricate and can present quality control and reliability issues. Many of these systems are not remotely configurable. Others utilize 3R regeneration (re-amplify, re-shape, re-time) which requires prior knowledge of the data format of the traffic, and, which results in loss of transparency.

There continues to be a need for more cost effective add/drop multiplexers which also exhibit improved reliability. Preferably such multiplexers could be used in a variety of network configurations. It would also be preferable if bit-rate transparency could be maintained in the optical paths.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates a portion of an exemplary network in accordance with the present invention;

FIG. **2**A illustrates an add/drop multiplexer in accordance with the present invention;

FIG. **2**B illustrates an alternate embodiment of the add/drop multiplexer of FIG. **2**A;

FIG. **3** illustrates details of an integrated receiver module usable in the add/drop multiplexer of FIG. **2**A;

FIG. **4** illustrates details of integrated transmitter module usable in the add/drop multiplexer of FIG. **2**A;

FIG. **5** illustrates a portion of an exemplary ring network which incorporates transceivers of a type illustrated in FIG. **2**B;

FIG. **6** illustrates a portion of an exemplary tree network formed of a plurality of nodes incorporating transceivers of a type illustrated in FIG. **2**B;

FIG. **7** illustrates a portion of an exemplary mesh network which incorporates transceivers of a type illustrated in FIG. **2**B; and

FIG. **8**A illustrates a portion of a known passive optical network; and

FIG. **8**B illustrates a higher capacity, active, form of the network of FIG. **8**A.

DETAILED DESCRIPTION

While this invention is susceptible of embodiment in many different forms, there are shown in the drawing and will be described herein in detail specific embodiments thereof with the understanding that the present disclosure is to be considered as an exemplification of the principles of the invention and is not intended to limit the invention to the specific embodiments illustrated.

Integrated optical component design and manufacturing techniques where multiple device functions are integrated onto a single device can be used to implement cost-effective add/drop multiplexers. Each integrated device replaces many discrete components. This leads to fewer spare parts and reduced manufacturing cost for the multiplexers. This approach reduces over-all system component cost because a large portion of the cost for such devices is typically associated with device packaging and fiber connections to the device. A crosspoint switch can be combined with the integrated devices at the respective nodes to provide remote configurability of the respective multiplexer and the network.

The multiplexers perform optical-electrical-optical conversions (through the use of transponder like regeneration) for all wavelengths including the pass-through wavelengths. The process regenerates all light paths at each multiplexer, on a per path basis, and eliminates the need for complicated link budget calculation and span engineering rules. The span engineering rules are required for some known versions of multiplexers that have optical pass-through.

The per path or wavelength regeneration allows for addition-deletion of nodes in the network without affecting the power budget of existing nodes. The conversion also permits wavelength switching to avoid stranded bandwidth, which is a problem for non-wavelength switching systems.

The multiplexers can be incorporated in ring networks. Protection schemes are allowed in this implementation.

A plurality of these integrated devices can be combined with a crosspoint switch to create larger degree nodes. In one embodiment, tree networks and mesh networks can be created. Such a tree network would correspond to a WDM version of a Passive Optical Network.

2R regeneration (re-amplify, re-shape) can be incorporated into respective devices without re-clocking (re-time) instead of 3R regeneration which requires clock recovery. 2R regeneration supports bit-rate transparency and permits each wavelength to operate at different bit-rates. This type of process was disclosed in Green, Jr. U.S. Pat. No. 5,483,372, now assigned to the assignee hereof.

In one disclosed embodiment, an integrated, arrayed, transmitter chip incorporates a plurality of K mono-chromatic sources, lasers, each operating at a different WDM wavelength, in combination with an integrated wavelength multiplexer on a common substrate. This chip has one fiber interface as compared to the discrete version which has 2K+1 fiber interfaces (one for each transmitter and K+1 for the multiplexer). An arrayed transmitter chip can be expected to be less costly than its discrete equivalent.

An arrayed receiver chip combines an integrated plurality of detectors with integrated waveguides coupled to an integrated wavelength demultiplexer on a common substrate. This chip can also be expected to be less expensive than the discrete counterpart. A plurality of transimpedance amplifiers and series coupled limiting amplifiers can also be integrated into the chip in order to 2R regenerate (reamplify, reshape) all received signals on a per wavelength (per lambda) basis.

According to another disclosed embodiment, a plurality of these chips are incorporated in an optical communication system. A crosspoint switch can be located between a receiver chip and a transmitter to add/drop or switch specific channels. The integrated chips reduce system cost while the crosspoint switch provides remote provisioning of light paths.

In the transmitter integrated lasers are provided on a per path or wavelength basis as optical sources. Laser drive electronics can also be integrated into the transmitter chip.

FIG. **1** illustrates a portion of an exemplary mesh network **10** that contains multiple electrical add/drop nodes **12***a, b*-n. These can, but need not, be substantially identical. Each add/drop module has fiber interfaces that accept and transmit WDM traffic via optical fibers **20***a, b, n*. One or more WDM channels can be added or dropped. Once dropped, the electrical signal can be retimed. At the intermediate add/drops, "through" traffic is not retimed. 2R reamplification and reshaping is provided thereby preserving bit rate transparency.

Each add/drop node includes wavelength multiplexers and demultiplexers to combine and separate the wavelength channels. Photodiode receivers for example PIN photodiodes, and directly modulated laser transmitters electrically regenerate received signals and then convert them back to an optical format. A crosspoint switch can be used to add and drop traffic.

FIG. **2**A illustrates details of a representative add/drop module, such as module **121**. Module **121** includes an integrated opto/electrical circuit receiver module **24**, an integrated electrical/optical circuit transmitter module **26** and an electrical switching fabric, which could be implemented as a crosspoint switch, **28**. Receiver module **24** is contained in a housing **24***a* and provides an optical input interface for an optical fiber **30** which might carry, for example, a WDM optical input signal, and a plurality of wavelength demultiplexed electrical output signals **32** which correspond to the channels (lambda) of the optical input signal. The module **24** includes a plurality of internal, integrated optical/electrical paths which are formed as integrated components on/in a common receiver circuit substrate **24***b*.

Transmitter module **26** is contained in a housing **26***a* and provides a multipath electrical interface for receipt of a plurality of electrical input signals **36** which in turn are each converted internally to an optical format, multiplexed and output to an optical output fiber **38**. The integrated circuit **26** includes a plurality of internal, integrated electrical/optical paths which are formed as integrated components on/in a common transmitter circuit substrate **26***b*.

The electrical switching fabric **28** provides a remotely alterable electrical interface **40** to electrical layers of the network whereby one or more WDM channels can be added or dropped. The switch fabric **28** facilitates remote reconfiguration of the respective node in accordance with traffic requirements.

It will be understood that switch fabric **28** could be replaced with a plurality of hardwired electrical paths. In this embodiment, the network will not be reconfigurable.

FIG. **2**B illustrates integrated circuit transceivers **14***a, b* which can be identical. Each includes a receiver **24-1** and a transmitter **26-1**, in accordance with receiver **24** and transmitter **26**, in a respective package **14***a***-1**, **14***b***-1**. The transceivers **14***a, b* can be used as an alternate to receiver module **24** and transmitter module **26** to implement a bi-directional node, or to provide a single package implementation. Additionally, higher degree nodes in bi-directional networks, discussed subsequently, can be implemented using transceiver elements **14***a, b*.

FIG. **3** illustrates details of integrated receiver module **24**. It will be understood that a variety of known fabrication techniques can be used to implement receiver **24**. Such details are not limitations of the present invention.

Receiver module **24** includes the substrate **24***b* which carries an optical wavelength demultiplexer **42** which converts for example, a WDM optical input signal on fiber **30** to a plurality **30***a* of information carrying output optical signals of differing wavelengths λ**1**, λ**2** . . . λn. The members of the plurality of optical signals **30***a* are each coupled via respective members of a plurality of waveguides **30***b*, integrally formed on/in substrate **24***b* to respective members of a plurality of opto/electric converters **30***c*. The members of plurality **30***c*, which could be relatively inexpensive PIN photodiodes, are integrally formed on/in substrate **24***b*.

The parallel electrical outputs from the members of the plurality **30***c*, each an electrical representation of a demultiplexed WDM channel, are coupled via a plurality of conductive elements **30***d* integrally formed on/in substrate **24***b* to respective inputs of members of a plurality of gain or regeneration elements **30***e*.

Outputs from each photodiode, such as **30***c-i* are coupled to a respective amplifier element **30***e-i* which provides both reamplification and reshaping (2R regeneration) of the electrical representation of the electrical signal from respective converter **30***d-i*. It will be understood that a variety of amplifier structures are usable in receiver **24** without departing from the spirit and scope of the present invention. For example and without limitation, the members of the plurality **30***e* could each be integrally formed on/in substrate **24***b* as a transimpedance amplifier coupled in series with a limiting amplifier.

Outputs from receiver **24**, a plurality of reamplified and reshaped electrical signals **32** can then be coupled to and switched via switching fabric **28** as discussed previously. Each optical channel, or wavelength, is reshaped electrically on a per channel basis avoiding known problems associated with mere amplification of a composite, WDM light beam.

One of the advantages of the configuration of receiver **24** is that the integrated combination of the multiplexer **42**, optical waveguides **30***b*, converters **30***d* and amplifier circuitry **30***e* consolidate extensive connectivity into a single integrated circuit, This in turn reduces packaging costs, reduces the number of fiber interfaces, and reduces inventory costs. Additionally, because of being able to take advantage of highly sophisticated integrated circuit manufacturing techniques, modules, such as the receiver **24**, can be expected to exhibit enhanced reliability and uniformity due to extensive reduction in discrete, manufactured connections.

FIG. **4** illustrates details of the integrated/transmitter module **26**. Transmitter module **26** incorporates a plurality of drive circuits **36***a*, one for each wavelength of interest, integrated on substrate **26***b* and a plurality of mono-chromatic sources, such as laser diodes or lasers, **36***b*. Each of the members of the plurality **36***a*, corresponding for example to **36***a***-1**, is in turn coupled to a respective member of the plurality **36***b* such as the member **36***b***-1**. In response to electrical input signals on the respective input such as input **e1**, I, the members of the plurality of lasers **36***b* emit modulated optical signals of appropriate wavelength, **λ1**, **λ2** . . . **λ1**, which in turn are coupled by a plurality of waveguides **36***c*, integrated on/in substrate **26***b*, to integrated optical multiplexer **44**. The composite optical signal output from multiplexer **44** is in turn coupled to optical fiber **38**.

It will be understood that the members of the plurality of drive circuits **36***a* can be implemented with various configurations without departing from the spirit and scope of the present invention. Similarly, the sources **36***b* also can be implemented in various ways without departing from the spirit and scope of the present invention.

Where one or more receiver modules **24** is electrically coupled to one or more switching fabrics, such as switch **36**, which is in turn coupled to one or more output modules **26**, optical signals on fiber **30** can be passed through to fiber **38**, or dropped via network **36**. Signals can be added via network **36** to the composite optical signal on fiber **38**. A variety of rates and data formats are simultaneously supportable by the configuration of FIG. **2**A in view of the 2R regeneration. Additionally, the configuration of FIG. **2**A is remotely configurable.

The configuration of FIG. **2**A permits wavelength conversion. This results in flexibility in wavelength assignment, and elimination of wavelength blocking or stranded bandwidth. Additionally, signals exhibit uniform power levels given per channel electrical regeneration. Nodes can be added or deleted readily using the structure of FIG. **2**A. Finally, the 2R regeneration provides for and supports protocol transparency. If desired, 3R regeneration, with reclocking could also be used without departing from the spirit and scope of the invention.

FIG. **5** illustrates diagrammatically a portion of an exemplary ring-type network **60** which can incorporate one or more optical fibers **60***a*, in the ring for redundancy and back-up. Hub node **62***a*, which can be implemented with a pair of transceivers **14***a*, **14***b* as illustrated in FIG. **2**B combined with an electronic switch, such as a crosspoint switch **28** can be used for the purpose of initiating and terminating optical signals on ring **60**. In such event, electrical input/output port pairs **64***a, b* can be used for purposes of adding and dropping signals on ring **60**.

A plurality of access nodes **66***a*, **66***b* and **66***c*, implemented using transceivers **14***a, b* can be coupled to the fiber **60***a*. In such event, for example add/drop multiplexers **66***a, c* coupled to fiber **60***a* could be used to add and drop selected wavelengths indicated as **60***b* transmitted by fiber **60***a* via respective add/drop ports **66***a***-1**, and **66***c***-1**. Similarly, access node **66***b* can be used to add/drop other wavelengths illustrated as **60***c* via add/drop port **66***b***-1**. Other variations are possible.

FIG. **6** illustrates a portion of an exemplary tree network **80** implementable with network nodes which incorporate a crosspoint switch such switch **28'** in combination with multiple identical transceiver modules **14***a* and **14***b*. The modules **14***a*, **14***b* can be linked via optical fibers such as the fibers **82***a*, **82***b*, **82***c*, **82***d* . . . **82***n*. It will be understood that a variety of tree configurations could be implemented using transceiver modules **14***a, b*, and associated switching element, such as switching element **28'**, without departing from the spirit and scope of the present invention. Using the switching elements **28'**, wavelengths can be routed to various nodes of network **80**.

FIG. **7** illustrates a portion of an alternate multiple transceiver array network configuration **90** wherein a quad transceiver configuration is used to implement each of the network nodes such as nodes **90***a, b, c*, and *d*. Each of the nodes, such as the node **90***a*, can be implemented with four transceiver modules, such as the transceiver module **14***a* combined with a respective switch element, such as the switch element **28'**. Using the switching elements **28'**, wavelengths can be routed to various nodes of network **90**.

Those of skill will understand that in many wavelength division multiplex systems optical channel spacing has been standardized at 50 GHz, 100 GHz, and 200 GHz. Additionally, course wave division multiplexing (CWDM) is known wherein the channels are spaced on the order of 20 nanometers apart. It will be understood that all such spacings are compatible with and come within the scope of the present invention.

FIG. **8**A illustrates a portion of a known form of passive optical network **100**. Such networks as known to those of skill in the art are configured as tree networks with an optical line terminal **102** forming a base thereof. Optical networking units **104***a, b, c, d* form leaves, terminations, for the network **100**.

The base and the leaves are interconnected by pairs of optical fibers, for example, optical fibers **110***a* and **110***b*. As known to those of skill in the art, in such networks, a single wavelength is transmitted unidirectionally in each optical fiber. The signals on a given optical fiber, such as fiber **110***c*, are split at passive optical splitters, such as splitters **114***a, b* into signals **110***c'*.

The passive nature of networks **100** limits both the information carrying capacity thereof as well as the geographical extent of such networks. However, the optical fibers supporting such networks have been installed and are an available resource.

FIG. **8**B illustrates a portion of an up-graded, higher capacity version **120** of the network **100**. The network **120**, as discussed below, has the advantage that it can utilize existing installed fiber links such as the links **110***a, b, c, c'* and c".

In the network **120**, the optical splitters **114***a, b* have been replaced by links of optical fiber **124***a, b, c* and **126***a, b, c*. These links join fibers, such as fibers **110***d, f* and **100***e, c"* which transmit signals in opposite directions relative to respective removed splitter **114***b*. This converts the network configuration **100** from a tree structure to a collapsed ring.

The passive optical network terminals and networking units **102**, **104***a, b, c, d* are also replaced with optical add/drop multiplexer units, **130***a*, . . . *e* which could be implemented in the form of integrated receivers and transmitters **24**, **26** combined with switch fabric **28**, discussed previously. Alternately, the add/drop nodes **130***a, b*, . . . *e* could be implemented using discrete components. Each of the add/drop nodes, such as **130***a*, incorporates a reconfigurable switch fabric such as the point-to-point switch fabric **28** which provides add/drop functionality for signals being added to or dropped from the network.

The network **120**, in addition to utilizing the existing installed fiber optic links can be operated as a multiple wavelength higher capacity network than is the case for the network **100**. Additionally, the network **120** is reconfigurable by means of the reconfigurable switch fabrics **28**. Finally, the use of active amplifier elements in the add/drop modules **130***a, b* . . . *e* makes it also possible to extend the geographical extent of the network **120** beyond that which is possible with passive network **100**.

From the foregoing, it will be observed that numerous variations and modifications may be effected without departing from the spirit and scope of the invention. It is to be understood that no limitation with respect to the specific apparatus illustrated herein is intended or should be inferred. It is, of course, intended to cover by the appended claims all such modifications as fall within the scope of the claims.

The invention claimed is:

1. A wavelength division multiplexing communications system comprising:

a plurality of optical fibers; and

a plurality of integrated, optical add/drop modules, wherein each of the plurality of integrated, optical add/drop modules includes at least one integrated receiver module embodied as an integrated circuit chip that carries an optical input, coupled to a respective optical fiber, and a plurality of electrical outputs, the integrated circuit chip incorporating a wavelength demultiplexer, optical detectors, and a plurality of amplifier elements integrated into the integrated circuit chip, wherein each of the plurality of integrated, optical add/drop modules includes an integrated transmitter module embodied as another integrated circuit chip that carries a plurality of electrical input ports and an optical output, the other integrated circuit chip incorporating a plurality of drive circuits, monochromatic optical sources, and a multiplexer integrated into the other integrated circuit chip, each of the plurality of drive circuits corresponding to a wavelength of interest and coupled to a respective one of the monochromatic optical sources, and the optical output coupled to a respective optical fiber, and wherein each of the integrated circuit chip and the other integrated circuit chip includes a plurality of waveguides integrally formed on a respective substrate, each of the plurality of waveguides integrally formed on the integrated circuit chip coupled to a respective one of the optical detectors, and each of the optical detectors coupled to an input of a respective one of the plurality of amplifier elements to reamplify and reshape information carrying electrical signals on a per wavelength basis; and

a controllable electrical switching fabric for coupling some of the plurality of electrical outputs to some of the plurality of electrical input ports with signal input and output ports for inputting or outputting the information carrying electrical signals.

2. A wavelength division multiplexing communications system as in claim **1** wherein the plurality of optical fibers are configured in one of a mesh network, a tree network or a ring network.

3. A wavelength division multiplexing communications system as in claim **1** wherein the at least one integrated receiver module includes the wavelength demultiplexer coupled to the optical input at an input side and to some of the plurality of waveguides at a plurality of outputs with selected pairs of optical signals carried by respective ones of the plurality of waveguides optically spaced apart from one another a predetermined number of wavelengths.

4. A wavelength division multiplexing communications system as in claim **1** wherein the integrated transmitter module includes the multiplexer coupled to the optical output at an output side and to some of the plurality of waveguides at a plurality of outputs with selected pairs of optical signals carried by respective ones of the plurality of waveguides optically spaced apart from one another a predetermined number of wavelengths.

5. A wavelength division multiplexing communications system as in claim **1** wherein the controllable electrical switching fabric implements wavelength switching between the at least one integrated receiver module and the integrated transmitter module to minimize stranded bandwidth.

6. A wavelength division multiplexing communications system as in claim **1** wherein some of the plurality of integrated, optical add/drop modules include a common housing for pairs of the at least one integrated receiver module and the integrated transmitter module.

7. A collapsed ring network comprising:

a plurality of pairs of optical fibers, wherein members of one of the plurality of pairs of optical fibers transmit optical signals in opposite directions; and

an add/drop node on opposing ends of each of the plurality of pairs of optical fibers, the add/drop node further comprising an integrated receiver module embodied as an integrated circuit chip, an integrated transmitter module embodied as another integrated circuit chip, and a controllable electrical switching fabric connecting the integrated receiver module and the transmitter module,

wherein some of the plurality of pairs of optical fibers terminate at a respective add/drop node while others of the plurality of pairs of optical fibers are coupled via a corresponding add/drop node to selected ones of the plurality of pairs of optical fibers to link the others of the plurality of pairs of optical fibers and the selected ones of the plurality of pairs of optical fibers that are transmitting signals in a common direction,

wherein the integrated circuit chip of the integrated receiver module includes a wavelength demultiplexer, a plurality of receiver module waveguides, a plurality of optical detectors, and a plurality of amplifier elements, the wavelength demultiplexer coupled to each of the plurality of receiver module waveguides, each of the plurality of receiver module waveguides coupled to a respective one of the plurality of optical detectors, and each of the plurality of optical detectors coupled to a respective one of the plurality of amplifier elements to reamplify and reshape electrical signals on a per wavelength basis, and

wherein the another integrated circuit chip of the integrated transmitter module includes a plurality of drive circuits, a plurality of monochromatic optical sources, a plurality of transmitter module waveguides, and a multiplexer, each of the plurality of drive circuits corresponding to a wavelength of interest and coupled to a respective one of the plurality of monochromatic optical sources, each of the plurality of monochromatic optical sources coupled to a respective one of the plurality of transmitter module waveguides, and each of the plurality of transmitter module waveguides coupled to the multiplexer.

8. A collapsed ring network as in claim **7** wherein the add/drop node includes signal add/drop ports, and wherein added signals are circulated through the collapsed ring network to be dropped at the respective add/drop node.

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